AD NUMBER

AD849443

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to DoD and DoD contractors only; Foreign Government Information; JUL 1968. Other requests shall be referred to British Embassy, 3100 Massachusetts Avenue, NW, Washington, DC 20008.

AUTHORITY

DSTL, DSIR 23/36825, 8 Dec 2008

849443

TECH. MEMO
471

ROCKET PROPULSION ESTABLISHMENT

THE TENSILE PROPERTIES OF SOME STRUCTURAL MATERIALS IN THE TEMPERATURE RANGE 293°K TO 20°K

PART II ALUMINIUM ALLOY SHEET D74S WP

by

P. Midgley

R. W. Thackray

July 1968

U.D.C. 539.42 : 620.172.251.1 : 669.715

ROCKET PROPULSION ESTABLISHMENT

WESTCOTT

Technical Memorandum 471

July 1968

THE TENSILE PROPERTIES OF SOME STRUCTURAL MATERIALS IN THE TEMPERATURE RANGE 293°K TO 20°K: PART II, ALUMINIUM ALLOY SHEET D74S WP

by

P. Midgley

R. W. Thackray

SUMMARY

The tensile properties of the aluminium alloy sheet D74S WP have been measured at temperatures of 293, 77 and 20°K. Plain and notched specimens from the longitudinal and transverse directions of the sheet were tested.

The results indicate that the alloy can be used in structures operating at temperatures down to 77°K.

CONTENTS

1 INTRODUCTION

The use of liquid hydrogen, fluorine and oxygen, with boiling points of 20°K, 86°K and 90°K respectively, as propellents in high energy propulsion systems, and also the application of other liquid gases in commercial projects has led to an increased interest in the physical and mechanical properties of constructional materials over a range of temperatures from 293°K down to 20°K.

The mechanical properties of materials at these extremely low temperatures vary considerably. The strength of most materials increases as the temperature decreases, but unfortunately this is usually accompanied by a decrease in toughness, i.e. a reduction in the material's resistance to brittle failure.

The main requirements that any material must fulfil before it can be applied in highly stressed components or structures operating at cryogenic temperatures are that it should

(a) have a high strength/density ratio,
(b) have adequate toughness
(c) be weldable and easily fabricated, and
(d) be readily available, preferably at low cost.

Much effort has been expended in the U.S.A. on evaluating both metallic and non-metallic materials over the temperature range 293°K down to 20°K[1,2,3,4]. It is unfortunate that, in general, there is no direct correlation between the chemical and mechanical specifications of U.S. and U.K. materials. Small changes in chemical composition and processing can give rise to marked differences in the mechanical properties of a material at low temperatures. For this reason it is necessary to measure the properties of U.K. materials which have potential applications. This Memorandum, one of a series[5], presents the results obtained from the evaluation of D74S WP aluminium alloy sheet.

2 EXPERIMENTAL

2.1 Facilities

The low temperature testing laboratory and experimental equipment for measuring the tensile properties of materials over the temperature range 293°K down to 20°K have been described fully elsewhere[6].

2.2 Material

D74S, an alloy of aluminium-4.5% zinc - 1.25% magnesium, was supplied by Alcan Industries Ltd. In the fully heat treated condition it has an ultimate tensile strength varying from 300 MN/m^2 (19 ton f/in^2) to 380 MN/m^2 (25 ton f/in^2) at 293°K. The chemical composition of the alloy evaluated is given in Table 1 along with the equivalent French alloy AZ5G for comparison[7].

Provided that the correct welding procedures are employed, D74S can be readily welded. Comparatively high joint efficiencies can be obtained in the weld region due to a recovery in strength of the heat-affected zone by natural ageing. If a full heat treatment is carried out after welding 100 per cent joint efficiencies are possible.

2.3 Test specimens

Two types of test specimen, shown in Fig.1, were used. A "pipped" test piece was used to determine the tensile properties, and a "notched" test piece for the evaluation of toughness.

2.3.1 "Pipped" test piece

The pips on the gauge length were used to locate and attach the extensometer arm assembly simply and accurately. Specimens were taken from the sheet in both the longitudinal and transverse directions relative to the direction of rolling during manufacture. For each configuration, two specimens were tested at 293°K and three specimens at 77°K (the boiling point of liquid nitrogen) and at 20°K. In all tests the strain rate was 0.005 $minute^{-1}$ to determine the proof stress and subsequently 0.05 $minute^{-1}$ to fracture.

2.3.2 "Notched" test piece

The root radius of the notches was 0.05-0.075 mm (0.002-0.003 inch), giving a stress concentration factor (K_t) of 6.3. This value of K_t was selected because

(i) it had been used extensively in U.S. programmes evaluating material behaviour at cryogenic temperatures, and

(ii) it is thought to be more sensitive in differentiating between tough and brittle materials[3].

3 RESULTS

The results of tensile tests for unnotched specimens tested in the longitudinal and transverse directions are given in Table 2, and for notched specimens in Table 3. Comparative data on an equivalent French material, AZ5G[7],

are presented in Table 4. The variation in the tensile properties of D74S WP with temperature are shown in Fig.2, and the appearance of the fractured test pieces in Figs.3 and 4.

4 DISCUSSION

The properties of D74S WP in the longitudinal and transverse directions showed a similar variation with temperature. The ultimate tensile strength increased markedly from 305.8 MN/m^2 (19.8 ton f/in^2) at 293°K to 514.3 MN/m^2 (33.3 ton f/in^2) at 20°K, whilst the variation in proof stress was smaller, increasing from 264.1 MN/m^2 (17.1 ton f/in^2) to 332.1 MN/m^2 (21.5 ton f/in^2) over the same temperature range. The ratio of Notched Tensile Strength/ Ultimate Tensile Strength (N.T.S./U.T.S.) was greater than unity down to approximately 50°K, but at 20°K it had decreased to a value of 0.79 and 0.84 for longitudinal and transverse specimens respectively. A value of the N.T.S./U.T.S. ratio of less than unity is considered to be an indication that the material is becoming brittle and less resistant to crack propagation. This latter tendency is confirmed by the appearance of the fracture surfaces of the notched test pieces (Fig.4). Specimens tested at 293°K failed in a completely ductile manner by shear accompanied by plastic deformation. The fracture surfaces of specimens broken at 77°K and 20°K, however, comprised two regions; the first, adjacent to the root of the notch, indicates that the crack had initially propagated in a brittle manner under plane strain conditions, and the second region that the mode of propagation had changed to a ductile shear mechanism associated with plane stress conditions. The degree of brittle fracture in the test piece increases with decreasing temperature indicating that the material becomes more brittle as the temperature is lowered.

An unusual feature of the results is the increase in total elongation of the specimen with decreasing temperature, ranging from 10 per cent at 293°K to a maximum of 27 per cent at 20°K. From the discussion of the results and the conclusion already reached that the material becomes more brittle at low temperatures, a decrease in total elongation would be expected. The reason for this discrepancy is not obvious. It could be caused by the notched specimens being broken in a bi-axial stress system, whereas in the conventional tensile test the specimen is subjected to a uni-axial stress. Attention should be given therefore to the influence of multi-axial stresses on the brittle behaviour of aluminium alloys and components at cryogenic temperatures.

5 CONCLUSIONS

The medium strength aluminium alloy sheet D74S WP can be used safely in the construction of components operating at temperatures down to 77°K. A more extensive testing programme would be required before it could be decided whether the material was suitable for use at temperatures below 77°K.

The trend in the properties of D74S WP with decreasing temperature from 293°K to 20°K, for both longitudinal and transverse specimens can be summarised by the following characteristics:

(a) a slight increase in the 0.2 per cent proof stress from 260 MN/m^2 to 330 MN/m^2.

(b) A more marked increase in the U.T.S. from 305 MN/m^2 to 515 MN/m^2.

(c) A pronounced increase in total elongation from 10 per cent to 27 per cent.

(d) A N.T.S./U.T.S. ratio greater than unity above 50°K.

Table 1

CHEMICAL COMPOSITION OF D74S AND AZ5G ALUMINIUM ALLOYS

Material	Quantity of alloying element, per cent								
	Fe	Cu	Si	Mn	Mg	Ti	Cr	Zn	Zr
D74S	0.28	0.01	0.11	0.25	1.37		0.13	4.53	
AZ5G	0.25	0.01	0.07	0.23	1.15	0.03	0.19	4.79	0.16

Table 2

TENSILE STRENGTH OF D74S WP ALUMINIUM ALLOY

THICKNESS 1.2 mm (0.048 in)

Temp., °K	Proof stress, MN/m^2			U.T.S., MN/m^2	Elongation on 50.8 mm, per cent	Modulus of elasticity, GN/m^2
	0.1%	0.2%	0.5%			
Longitudinal (in direction of rolling)						
293	259	264	269	306	11.0	68.2
77	287	295	301	389	21.6	76.1
20	323	334	343	514	33.4	75.8
Transverse (perpendicular to direction of rolling)						
293	250	258	266	304	10.0	68.4
77	279	292	304	392	19.4	69.8
20	320	332	346	528	27.1	72.0

Temp., °C	Proof stress, ton f/in^2			U.T.S., ton f/in^2	Elongation on 2 inches, per cent	Modulus of elasticity, 10^3 ton f/in^2
	0.1%	0.2%	0.5%			
Longitudinal (in direction of rolling)						
20	16.8	17.1	17.4	19.8	11.0	4.42
-196	18.6	19.1	19.5	25.2	21.6	4.93
-253	20.9	21.5	22.2	33.3	33.4	4.91
Transverse (perpendicular to direction of rolling)						
20	16.2	16.7	17.2	19.7	10.0	4.43
-196	18.1	18.9	19.7	25.4	19.4	4.52
-253	20.7	21.4	22.4	34.2	27.1	4.66

Table 3

NOTCHED TENSILE STRENGTH OF D74S WP ALUMINIUM ALLOY THICKNESS 1.2 mm (0.048 in)

Temp., °K	Notched tensile strength (N.T.S.), MN/m^2	$\frac{N.T.S.}{U.T.S.}$	$\frac{N.T.S.}{0.2\% \text{ proof stress}}$
Longitudinal (in direction of rolling)			
293	337	1.10	1.27
77	428	1.09	1.45
20	406	0.79	1.22
Transverse (perpendicular to direction of rolling)			
293	349	1.15	1.35
77	429	1.11	1.47
20	442	0.83	1.34

Temp., °C	Notched tensile strength (N.T.S.), ton f/in^2	$\frac{N.T.S.}{U.T.S.}$	$\frac{N.T.S.}{0.2\% \text{ proof stress}}$
Longitudinal (in direction of rolling)			
20	21.8	1.10	1.27
-196	27.7	1.09	1.45
-253	26.3	0.79	1.22
Transverse (perpendicular to direction of rolling)			
20	22.6	1.15	1.35
-196	27.8	1.11	1.47
-253	28.6	0.83	1.34

Table 4

MECHANICAL PROPERTIES OF THE ALUMINIUM ALLOYS

D74S WP AND AZ5G-T6

Temp., °K	Direction of test	Material	0.2% proof stress		U.T.S.		N.T.S.		Elongation, per cent
			MN/m^2	ton f/in^2	MN/m^2	ton f/in^2	MN/m^2	ton f/in^2	
293	Long.	D74S WP	264	17.1	306	19.8	337	21.8	11.0
	Trans.	D74S WP	258	16.7	304	19.7	349	22.6	10.0
		AZ5G-T6	324	21.0	373	24.2	422*	27.3*	18
77	Long.	D74S WP	295	19.1	389	25.2	428	27.7	21.6
	Trans.	D74S WP	292	18.9	392	25.4	429	27.8	19.4
		AZ5G-T6	412	26.7	520	33.7	540*	35.0*	21
20	Long.	D74S WP	334	21.5	514	33.3	406	26.3	33.4
	Trans.	D74S WP	332	21.4	528	34.2	442	28.6	27.1
		AZ5G-T6	432	28.0	628	40.7	618*	40.0*	24

*denotes $K_t = 4.8$

REFERENCES

No.	Author	Title, etc.
1		Mechanical properties of structural materials at low temperatures. N.B.S. Monograph 13, U.S. Government Printing Office (1960)
2	T. F. Durham R. M. McClintock	Cryogenic materials data handbook, 1940-59. N.B.S., Cryogenic Engineering Laboratory, Boulder, Col.
3		Low temperature properties of high strength aircraft and missile materials. A.S.T.M. Special Technical Publication No.287, Philadelphia 3, Pa., (1961)
4	J. E. Campbell	Aluminium alloys for cryogenic service. Materials Research and Standards, pp.540-548 (1964)
5	P. Midgley R. W. Thackray	The tensile properties of some structural materials in the temperature range 20°C to -253°C. Part I Aluminium alloy sheet HS30 WP. R.P.E. Technical Memorandum 426 (1967)
6	P. Midgley	A facility for the investigation of mechanical properties of materials in the temperature range +20°C to -253°C. R.P.E. Technical Memorandum 410 (1966)
7	R. Develay	Les alliages d'aluminium à moyenne ou haute résistance et leur comportement aux basses températures. Revue De L'Aluminium, Février, pp.193-215 (1966)

ATTACHED:

Drgs. RP4191, 4638-4640

DISTRIBUTION:

Mintech:

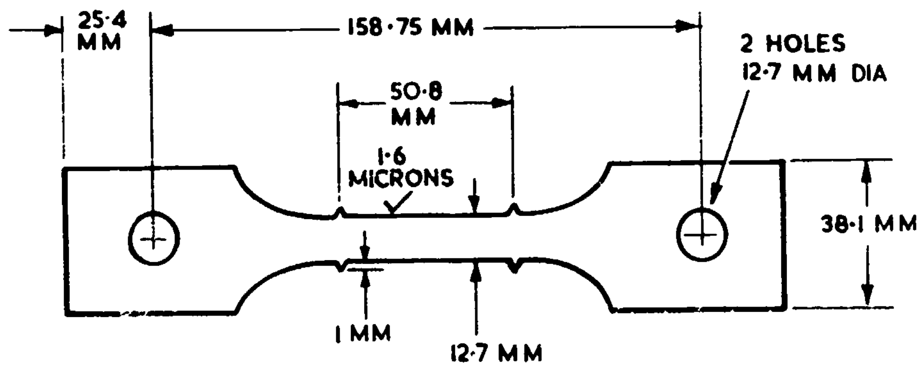
D/Mat & S	
D/Space	
AD/Eng RD5	
AD/GW(E)	2
AD/GW(X)	
AD/Space 2	
ERDE	3
RAE Farnborough	5
RRE	
NGTE	2
NEL	
NPL	
GW(C&C)5	21
I i/c AID, Harefield	
ARC Rocket sub-committee	35

Min Defence (Army):

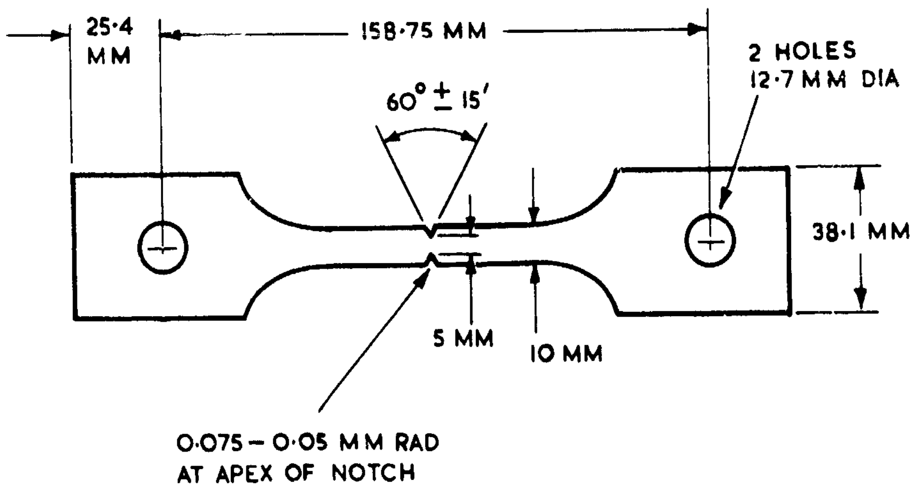
RMC Science	
RARDE	2

UKAEA:

AERE	2



(A) PIPPED TEST PIECE



(B) NOTCHED TEST PIECE

FIG. 1 TENSILE TEST PIECES

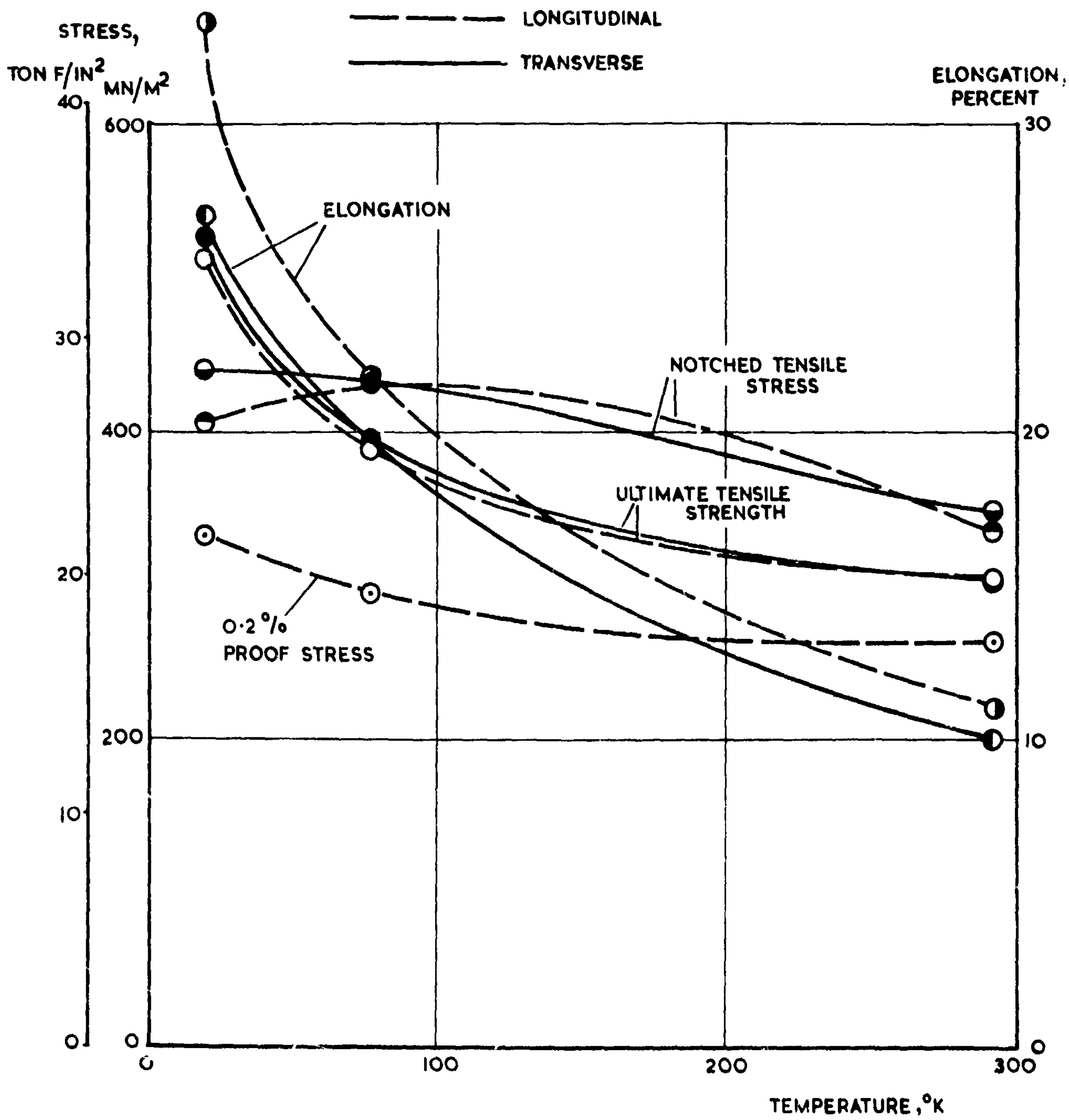
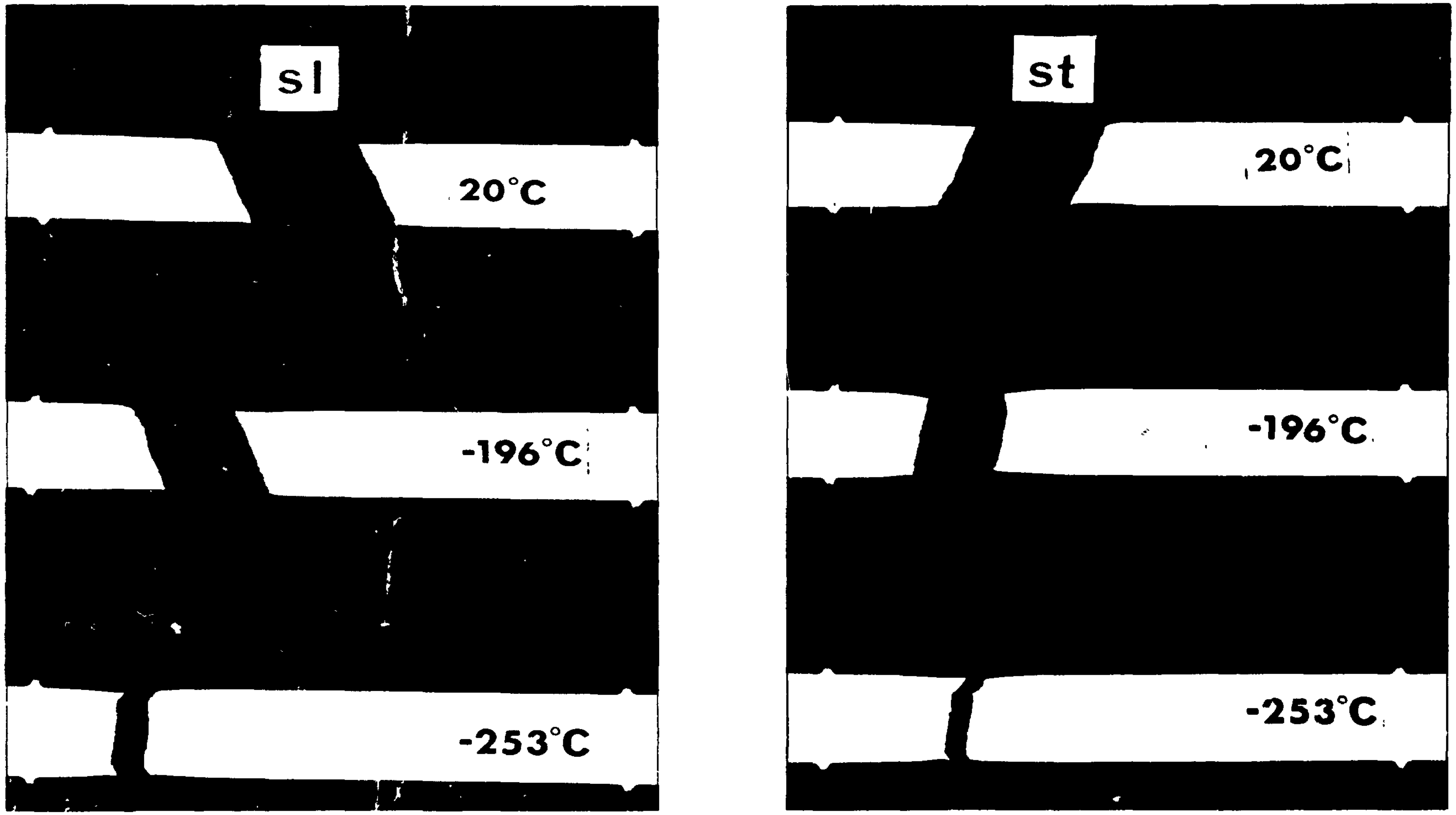


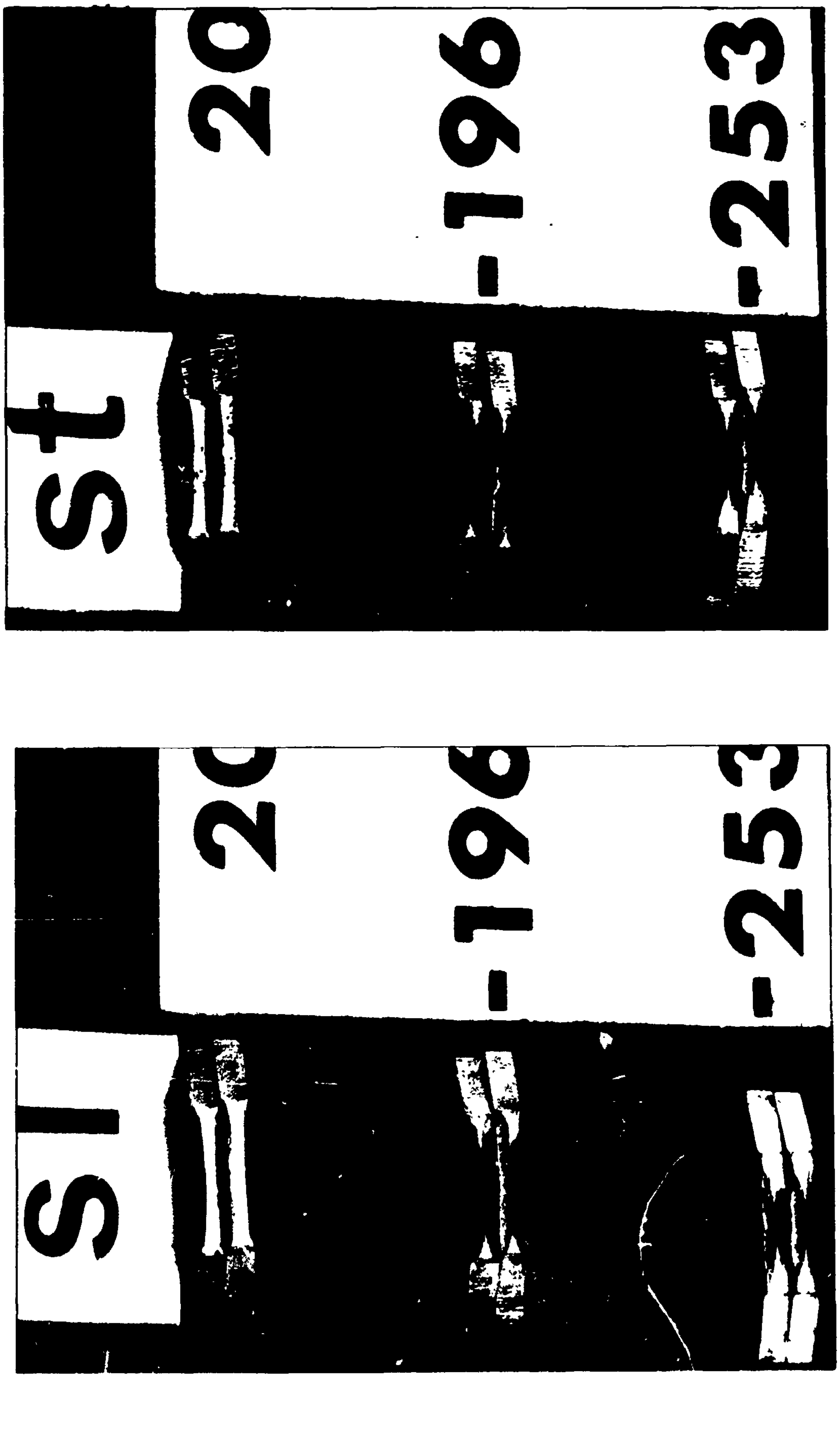
FIG. 2 VARIATION IN TENSILE PROPERTIES OF D745 WP
WITH TEMPERATURE



(A) LONGITUDINAL

(B) TRANSVERSE

FIG.3 TENSILE TEST PIECES AFTER TESTING AT DIFFERENT TEMPERATURES



(A) LONGITUDINAL

(B) TRANSVERSE

FIG.4 FRACTURE SURFACE OF NOTCHED TEST PIECE

Information Centre
Knowledge Services
[dstl] *Porton Down,*
Salisbury
Wilts
SP4 0JQ
22060-6218
Tel: 01980-613752
Fax 01980-613970

Defense Technical Information Center (DTIC)
8725 John J. Kingman Road, Suit 0944
Fort Belvoir, VA 22060-6218
U.S.A.

AD#: AD849443

Date of Search: 8 December 2008

Record Summary: DSIR 23/36825

Title: The Tensile Properties of Some Structural Materials in the Temperature Range 293 K to 20 K: Part II, Aluminum Alloy Sheet D74S WP
Availability Open Document, Open Description, Normal Closure before FOI Act: 30 years
Former reference (DepartmentRPE-TM-471, 31079
Held by The National Archives, Kew

This document is now available at the National Archives, Kew, Surrey, United Kingdom.

DTIC has checked the National Archives Catalogue website (http://www.nationalarchives.gov.uk) and found the document is available and releasable to the public.

Access to UK public records is governed by statute, namely the Public Records Act, 1958, and the Public Records Act, 1967.
The document has been released under the 30 year rule.
(The vast majority of records selected for permanent preservation are made available to the public when they are 30 years old. This is commonly referred to as the 30 year rule and was established by the Public Records Act of 1967).

This document may be treated as <u>UNLIMITED</u>.